SUMMARY OF THE SNOWMASS WORKING GROUP ON MACHINE-DETECTOR INTERFACE

V. BHARADWAJ, P. COLESTOCK, J. COOPER, G. GODERRE, J. HOLT
Fermi National Accelerator Laboratory
P. O. Box 500, Batavia, Il. 60510

1. MACHINE DETECTOR INTERFACE CONSIDERATIONS

From the detector point of view, what experimenters need is an outline of the EXPECTED machine parameters tempered with some indication of the POSSIBLE machine parameters. Given guidance from accelerator physicists on the machine, experimenters may get the germ of an idea of how to exploit a particular machine property. Similarly, given some indication of what is important to the experimenters, accelerator physicists may have ideas of how to modify the machine appropriately. We discuss below a list of machine parameters as viewed by experimentalists.

1.1. Luminosity

From the discussions in the other working groups at this workshop it is apparent that no planned experiment anticipates a wealth of data -- typical experiments are looking at B-physics in exclusive channels with small branching ratios. For example, to measure the CP Asymmetry angle beta, we hope to use the decay B --> $J/\psi + K^0_S$. The B branching ratio for this decay is only 4×10^{-4}. Then in addition the J/ψ--> 2 μ or 2 electrons branching ratio is only 0.06, the K^0_S --> π-π branching ratio is 0.68, the typical detector rapidity and P_t efficiencies are small, and the B must be tagged by seeing a lepton from the other B in the event. The typical overall efficiencies are of the order of 10^{-9}. Therefore the experimenter's demand for B-physics is for the largest possible integrated luminosity in the shortest possible time, i.e. for higher and higher luminosities.

1.2. Number of Bunches / Bunch Spacing

This parameter coupled with the luminosity gives the number of interactions per crossing seen by a detector. Here there are not many quantitative studies (in fact we are aware of no specific study on B-physics), but the gut feeling is that fewer interactions per crossing is better, since the detector information is then less confused. In high transverse momentum (P_t) physics (e.g. W, Z, top,...) these extra interactions are not expected to be a major headache since the extra particles in the event from the extra interactions are from minimum bias events and have typical Pts less than a few GeV compared to the phenomena being investigated. This confusion factor is likely to be more important for "soft" B-physics (decay products of 5 GeV object produced with low Pt) than it is for high Pt physics at the same accelerator.

Given a trigger on a rare event, the average number of extra interactions is the same as the number of interactions per crossing. Recall that the probability of n interactions per crossing is given by Poisson statistics, so the distributions have very long tails. The average number of interactions per crossing is only part of the story, and the number of triggered events with more than 3 extra interactions in the crossing can be large. See Table 1 for an example at the Tevatron at a luminosity of 10^{32}.

Table 1. Interactions of the Tevatron at luminosity 10^{32}

Bunch spacing (nsec)	number of bunches	average number of extra interactions	% with > or = 3 extra	% with > or = 6 extra	% with > or = 10 extra
3	6	15.4	100 %	99 %	90 %
396	36	1.8	25 %	1 %	-----
132	99	0.6	2 %	-----	-----

The bunch structure also has severe implications for the detector electronic read-out systems. It is worth noting that both CDF and DO at the Tevatron are attempting to build electronics in all systems capable of 132 nsec between crossings as part of the round of detector upgrades leading to Tevatron Collider Run II with 396 nsec spacing. The object is to build all this electronics once and avoid the need of another expensive upgrade later. It is important to understand the Tevatron bunch scenario for 132 nsec as these electronics designs are being frozen within the next year. For example, the required existence of an abort gap between some bunches may provide an opportunity for the experimenters in their design. How long are these abort gaps ? How many are seen at an interaction region ? Similar questions and answers should have an effect on B-detectors at the SSC.

1.3. Beam Energy

In our thoughts this is fixed at the SSC, but historically has been variable over a small range (546 GeV to 900 GeV, perhaps eventually even slightly higher) at the Tevatron. B cross sections rise with energy and larger statistical samples are always better -- this is one clear advantage of the SSC. It has been pointed out at this workshop that the theory prediction of the B cross section from CERN p-pbar to the Tevatron does not match the results reported by CDF. If the Tevatron could be operated with high luminosity at a lower energy, we could learn information vitally important to all the planned experiments at higher energy colliders.

1.4. Luminosity Lifetime

Experiments must cope with PEAK luminosities while the final physics results depend on the INTEGRATED luminosity. By setting a trigger threshold on some parameter, the experimenter triggers the detector on a fixed cross section and therefore the trigger rate is directly proportional to luminosity. As the luminosity decreases, the experimenters usually retaliate by lowering the parameter threshold so as to keep the trigger rate near the peak capability of the detector. However, the greatest INTEGRATED luminosity comes from the short periods at the highest luminosity, so the final experimental statistics on a given process are strongly coupled to the peak luminosity. Any effort which smooths the peak to valley ratio of luminosity is welcome.

1.5. β^*/ Longitudinal Emittance

These two parameters couple to give the length of the luminous region. At the Tevatron the region is very long (sigma of order 30 cm) and this complicates the experimental design of the silicon vertex detectors now at the heart of most collider detector b-physics strategies. For example the CDF SVXII is now designed as a 1.02 meter-long barrel to cover the rapidity range of η <1.0, while a device only 0.22 meters long would be required if the Tevatron were a longitudinal point source. At an estimated silicon barrel cost approaching 40 K$ per centimeter of length, this extended source problem translates directly into a lot of cash. Could changes in the RF or a small crossing angle help this situation without too much compromise in the luminosity ? Again, at the Tevatron, these devices are being designed now for Collider Run II and beyond, so feedback on the machine possibilities will be far more timely now than five years from now. The silicon detectors under design all have conceptual upgrade paths, so information on possible changes in the luminous region for far future collider runs is also useful.

1.6. Transverse Emittance

Experiments (e.g., CDF's SVT) now envision fast secondary vertex triggers based on silicon vertex detector information. The idea is to look for charged tracks with a large impact parameter when extrapolated to the transverse beam position, as expected if the track actually comes from a secondary vertex. Therefore these trigger devices depend on a small and stable transverse beam size. What are the expected (and possible) machine parameters ? Note that the presence of extra interactions in an event can confuse these triggers -- for example if you wished to make a secondary vertex cut at 100 microns with such a trigger and the tranverse beam size were already of order 100 microns, the trigger would select multiple interactions and not b-decays. Similarly, if the transverse beam spot moved by 100 microns between collider stores or during a single store, the trigger could be confused unless this transverse position information were available in real time. On the other hand if the experimenters assume a 50 micron beam size but 10 microns is possible, this can make a huge difference in the trigger design and performance. Clearly this is an area where the experimentalists and accelerator physicists must be on the same wavelength all the time.

2. SUMMARY OF TEVATRON PERFORMANCE - PAST, PRESENT AND PROJECTIONS

In this section we give a summary of Tevatron Collider performance, focussing on the recent Collider Run as it relates to the potential for future B-physics experiments at Fermilab. We consider the overall performance characteristics, and present specific issues concerning intensity limitations, lifetimes and beam stability.

2.1. Performance summary of the 1992-93 Tevatron Collider Run

The recently completed Collider Run has seen the successful implementation of separated orbits and simultaneous operation of two interaction regions. As a result of these and other improvements, the peak luminosity achieved was over a factor of four greater than previous levels and the average delivered luminosity exceeded 1 pb^{-1} / week. A plot of the integrated luminosity over the run, as compared to the previous run, is shown in Fig. 1

There was a steady increase in the initial luminosity, and in the integrated luminosity per store during the early phases of the run, which can largely be attributed to increases in the extracted number of pbars which achieved collision. The inital luminosity was observed to be essentially proportional to the number of available pbars, as shown in Fig. 2. In this figure, two different operating modes are depicted: the nominal $\beta^* = 0.5$ m and the $\beta^* = 0.25$ m, corresponding to two alternate low-beta insertion lattices in use.

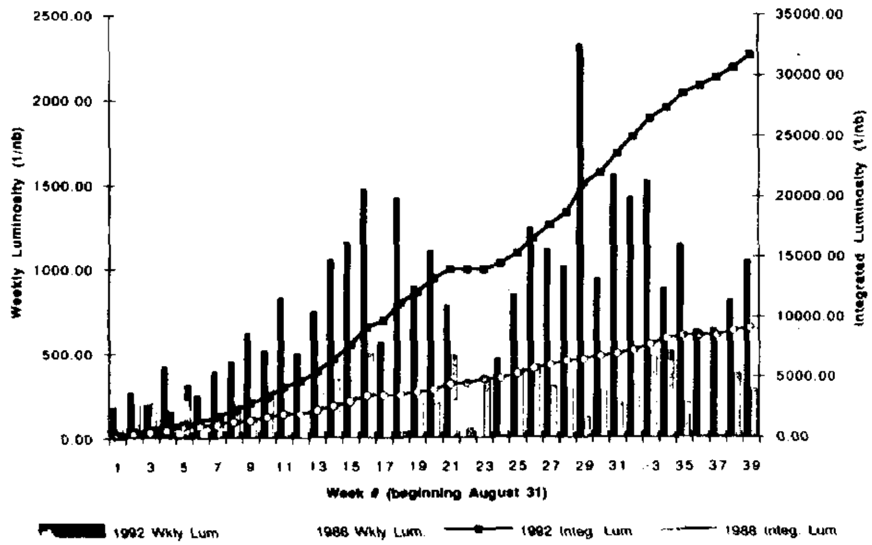

Figure 1. Integrated Collider luminosity for the 88-89 and 92-93 runs.

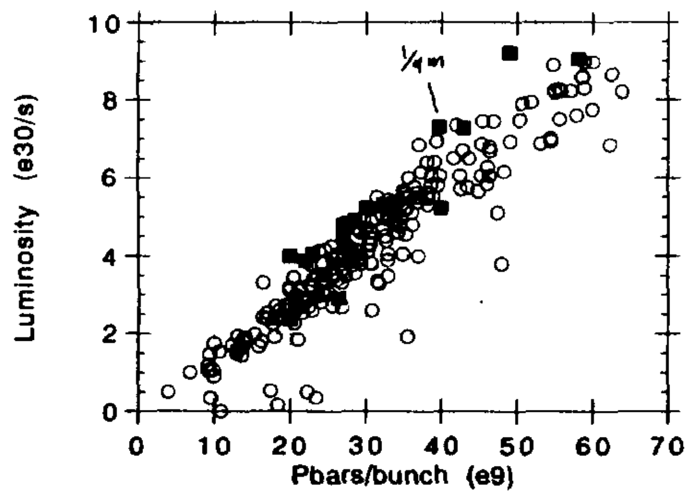

Figure 2. Initial luminosity as a function of pbars achieved at collision. Two operating modes are shown: the open circles are at $\beta^* = 0.5$ m and the solids are at $\beta^* = 0.25$ m.

Under typical operating conditions, initial luminosities in the range of 6-8 x 10^{30} cm^{-2} sec^{-1} were achieved accompanied by luminosity lifetimes in the range of 15 hrs, as shown in Fig. 3. The lifetimes were seen to be due primarily to emittance growth which, in turn, is believed to be caused by low-level power supply noise. Fig. 3 indicates that the lifetime is largely independent of luminosity, although there may be a slight degradation at lower β^* due to the fact that less time was spent finding and maintaining an optimal operating point under these conditions. The corresponding particle lifetimes are shown in Fig. 4, which shows the time evolution of protons and pbars during the course of three successive stores.

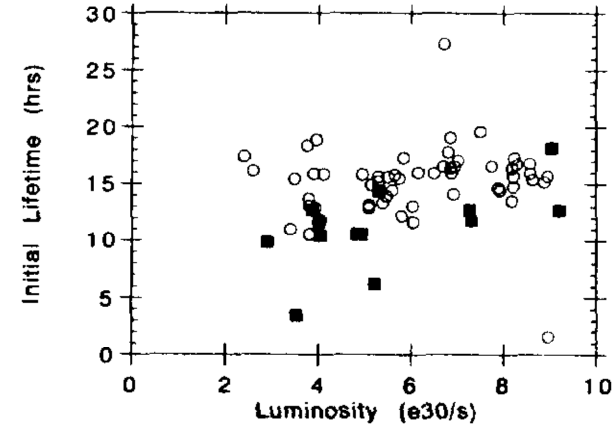

Figure 3. Initial luminosity lifetime as a function of the initial luminosity. The open circles correspond to $\beta^* = 0.5$ m and the solids correspond to $\beta^* = 0.25$ m.

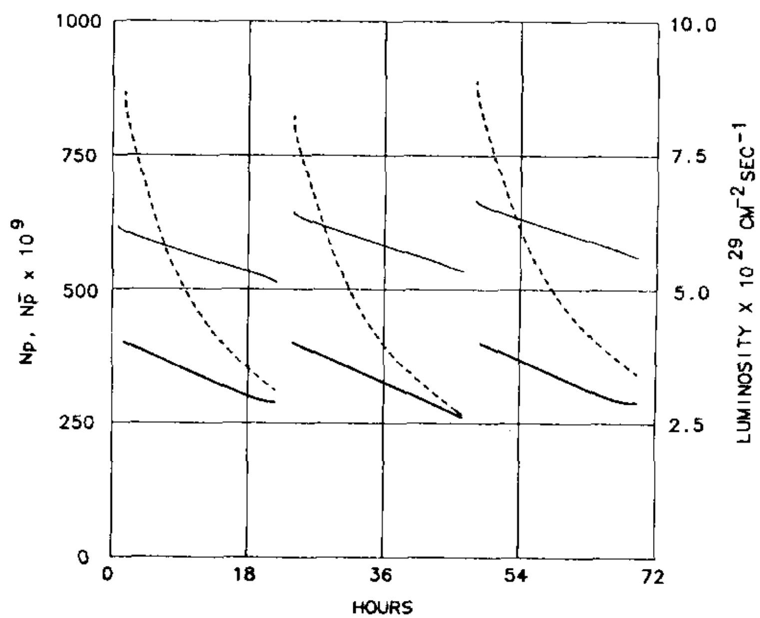

Figure 4. Time evolution of three successive Collider stores for particle intensities (protons, light solid, p-bars, heavy solid) and the measured luminosity (dashed). The dominant factor in the luminosity lifetime is due to emittance growth at the rate of 0.3 π / hr.

2.2 Operational Issues

In addition to the usual issues related to hardware reliability, there were a number of operational issues which affected the stability of the beam. The primary issue affecting operation was due to periodic drifts in the Tevatron orbit, and hence in the Tevatron operating point as a result of the nonlinear fields in the device, believed to be due primarily to the nonlinearities in the low beta quadrupoles. The position of the interaction region was observed to drift by as much as 200 microns over the course of several stores, accompanied by tune changes and, in some cases, changes in the particle lifetimes. Although not possible during this run, it is believed that such orbital changes can be controlled in future operation.

2.3 Projected Tevatron Operation

The operation of the Tevatron Collider follows three stages in the coming years, as shown in Table 1. The first of these stages, labelled 1B, involves the commissioning of a new, higher-energy Linac, accompanied by an expected gain of a factor of three in integrated luminosity. In Phase II, the number of bunches will be increased to 36 X 36, giving rise to an expected increase in luminosity of an additional 30%. Finally, in the Main Injector era, the integrated luminosity is expected to reach 20 pb^{-1}/wk.

Another mode of operation has been considered in which the bunch number is increased to 99 X 99. In order for such a mode of operation to be feasible, it is necessary to develop fast rise-time kickers. This option will be explored more fully in the following section.

2.4 Tevatron Bunch Loading

Presently the Tevatron collider operates with six proton and six pbar bunches spaced evenly around the ring (3500 nsec spacing). The bunches are loaded one at a time starting with the protons. Each bunch consists of eleven buckets coalesced into one which is done in the Main Ring. As the intensity per bunch increases, the number of interactions per crossing as seen by the experiments increases to an unacceptable level. Therefore in a future collider run, the Tevatron will switch to thirty-six bunch operation. How these bunches are loaded is constrained by a number of factors.

1. There must be a gap in the bunch train for the abort kickers to rise to their nominal voltage.

2. Both experiments (B0 and D0) must receive the same luminosity.

3. To use the present coalescing system, the bunches must be spaced no less than twenty-one buckets (396 nsec) apart.

4. No bunch-"air" collisions.

The constraints dictate a three-fold symmetry of three groups of twelve bunches spaced at twenty-one buckets within the group. Figure 5 shows this configuration at a particular moment in time. The abort gap is 2600 nsec which is smaller than the present gap of 3500 nsec. Development on shortening the rise time of the abort kicker is underway.

As with the present loading scheme, the protons would be loaded first. Twelve batches would be coalesced into twelve bunches spaced at 376 nsec. They would be injected into the Tevatron as a group. Three injections would fill the Tevatron. The present injection kickers are adequate for this purpose. The pbars however, are loaded in a different way. The pbar source will be modified extract four batches of pbars. These would then be coalesced in the Main Ring and injected into the Tevatron. This requires an injection kicker with a rise time of at least 376 nsec and a flattop time of at least 1224 nsec. A kicker meeting these requirements is under development.

For ninety-nine bunch operation in the Main Injector era and assuming two experiments, the injection kicker timing requirements become very stringent. The bunches would be grouped in three groups of thirty-three each with a bunch spacing of 131 nsec. Injection kickers would have to be developed with this rise time. Also there would have to be modifications to the Main Injector coalescing system as well as RF modifications to the pbar source. The protons could be loaded in batches of thirty-three but the pbars would be loaded twelve at a time.

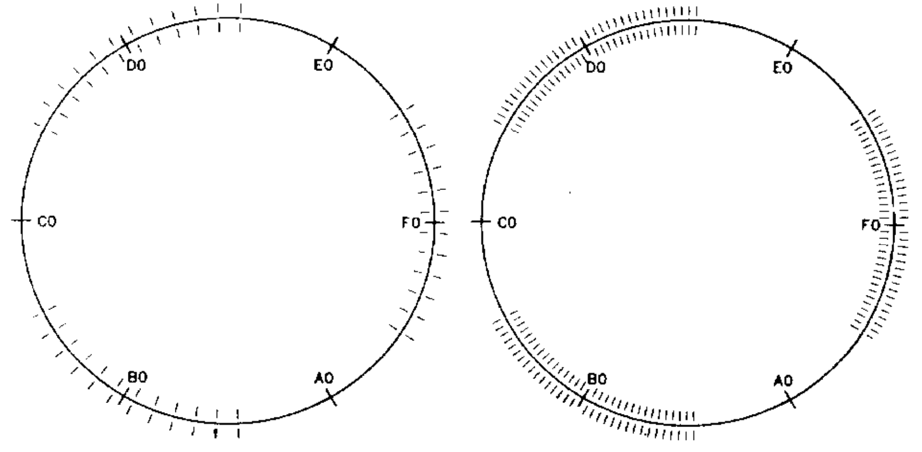

Figure 5 (a). Loading scheme for the 36 X 36 mode of operation. The bunches are arranged with three-fold symmetry and an abort gap sufficient to permit clean removal of the beam. (b) Loading scheme for 99 X 99.

2.5 Other Projected Improvements - Bunched-beam Cooling

A proposed scheme for improving the integrated luminosity is the use of stochastic cooling of the bunched-beam in the Tevatron. The process by which this is done is similar to that routinely carried out in anti-proton storage rings, but with the additional complication that the feedback signal must be carefully separated from the large coherent signals associated with the bunched beam. This project is now in development at Fermilab and if successful can significantly increase the integrated luminosity of a given store. The effect of a cooling time on the order of 20 hrs. can lead to a 50% increase in integrated luminosity, as shown in Fig. 6

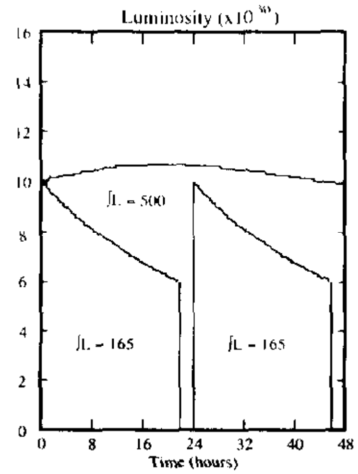

Figure 6. Simulation of Bunched-beam cooling. An increase in integrated luminosity of approximately 50% is realized with a 20 hr. cooling time

2.6 *Bunch Shortening*

In an effort to permit shorter bunches in the Tevatron, an investigation was undertaken to determine viable means of controlling bunch length. One scheme proposed was that of raising the rf frequency. However, upon further study it was determined that a much simpler method was to raise the rf voltage. The bunch length scaling with voltage is shown in Fig. 7. The associated scaling of the momentum spread is shown in Fig. 8.

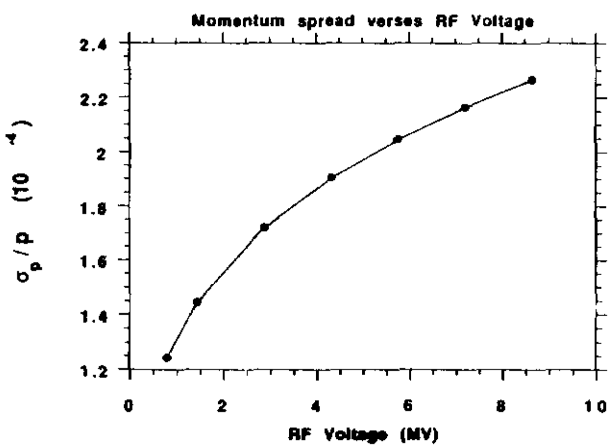

Figure 7. Bunch length scaling with rf voltage

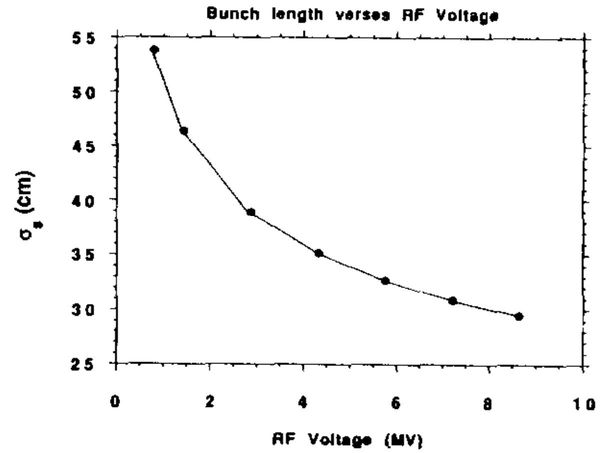

Figure 8. Momentum spread scaling with rf voltage

It should be noted that it is assumed that the Tevatron is well below instability thresholds such that the shorter bunch lengths do not present a stability problem for the Collider.